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EVALUATION OF TWO HIGH-CARBON PRECISION-CAST ALLOYS AT 1700° AND 1800° F BY THE RUPTURE TEST

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SUMMARY

Information regarding the performance of two precision-cast alloys at 1700° and 1800° F has been obtained by rupture tests. One alloy tested was essentially a 30-percent-nickel modification of alloy N155 with 1 percent carbon and the columbium replaced by 2 percent tantalum. The other alloy was the Vitallium analysis modified with 1.2 percent carbon and 2 percent tantalum. The two alloys were the NT-2 and VT2-2 types, respectively, developed for the Bureau of Ships, Navy Department, at the Massachusetts Institute of Technology. The NT-2 type alloy was heat treated prior to testing while the VT2-2 type alloy was left in the as-cast condition because their experience had shown that these conditions developed the best properties in the alloys.

The results obtained indicate that the NT-2 type alloy was stronger than the VT2-2 type alloy for time periods longer than 10 hours. The rupture strengths of the NT-2 type alloy compared favorably to those of the best alloy, X-40, previously tested at 1700° and 1800° F. The modified Vitallium alloy was superior in rupture strength to the standard Vitallium alloy for time periods up to about 1000 hours. Data from tests at 1500° and 1600° F made for the Bureau of Ships, Navy Department, at the Massachusetts Institute of Technology were used to show the effect of temperature on the properties of the alloys in the rupture test.

Stress-time-for-rupture data were plotted using stress and log rupture time as coordinates and also log stress and log rupture time as coordinates. On the semi-log plot the data were best represented by a single straight line, while on the log-log plot a break occurred in the straight-line relationship.

INTRODUCTION

The high temperatures required for efficient operation of the gas turbines used in aircraft engines have placed emphasis on the development of better heat-resisting alloys than are now available. Metallurgical research on heat-resisting alloys for this purpose is being conducted at the University of Michigan for, and with the financial assistance of, the National Advisory Committee for Aeronautics. The investigation covered by this report was undertaken at the request of the NACA Subcommittee on Heat-Resisting Alloys for the purpose of obtaining information regarding the strength and ductility of known alloys at 1700° and 1800° F.

Only a small amount of test or service data is available at these temperatures for the new alloys being developed by the various research programs in the country on materials for gas turbines. A previous report presented data from rupture tests at 1700° and 1800° F for several new cast and wrought alloys (reference 1). The present report extends this information to include two of the best alloys for buckets at 1500° and 1600° F devised in a study of materials for gas turbines made at the Massachusetts Institute of Technology for the Bureau of Ships, Navy Department, (references 2, 3, and 4). The rupture-test properties of the alloys at these temperatures were sufficiently high to warrant extending the data to 1700° and 1800° F.

The data presented in this report are primarily useful for informing the design engineer of the probable range in strength and ductility of available alloys at 1700° and 1800° F. The research metallurgist is also provided with a basis for the development and evaluation of new alloys. For instance, this report shows the effect of increasing the carbon content of alloys to a much higher level than is ordinarily encountered in heat-resisting alloys.

The curves of stress against rupture time are presented as both the familiar log-log curves and as curves of stress against the logarithm of the time for rupture. A recent fundamental analysis of the rupture test has indicated that the logarithm of the time for rupture is correctly related to stress rather than to the logarithm of the stress, the relation generally used in previous work (reference 5).

TEST MATERIALS

The samples were precision castings prepared by N. J. Grant at the Massachusetts Institute of Technology. The alloys were designated 97NT-2 and 113VT2-2 or 128VT2-2. Up to the time they were submitted for testing, these alloys had shown the best rupture-test properties at 1500° and 1600° F of a large number of alloys studied at the Massachusetts Institute of Technology.

The NT-2 type alloy is similar to N155 alloy except that the nickel is 30 percent rather than 20 percent, and 2 percent tantalum is substituted for the 1 percent of columbium. The number 97 indicates that the carbon content was 0.97 percent, which is much higher than the 0.30 percent in standard N155 alloy. The number 2 following the letters indicates that only residual nitrogen was present.

The VT2-2 type alloy is a modification of standard Vitallium alloy. The carbon content was 1.13 or 1.28 percent instead of the approximately 0.30 percent of Vitallium. This alloy also carried 2 percent tantalum.

Two heats of each alloy were submitted. Both heats of the 97NT-2 alloy had the same carbon content and were not kept separate. The VT2-2 heats had different carbon contents and were kept separate. Information regarding the details of the sample preparation and chemical analyses was also submitted.

Melting

Melting was done in a small electric-arc furnace in which losses by oxidation did not occur. The austenal casting process was used to produce specimens with a 1/4-inch diameter by 1-inch gage section. The molds were preheated to 1850° F. The samples were inspected for soundness by radiographic examination prior to submission for testing.

Chemical Composition

The analyses submitted with the specimens are given in table I. Carbon was the only element actually analyzed while the others were aim values. Experience in making the alloys indicated that the actual analysis would be quite close to the nominal composition.

Table I also includes chemical analyses of the specimens by the Union Carbide and Carbon Research Laboratories, Inc. Ends from broken specimens after rupture testing were supplied for the chemical analyses. The results agreed closely with the aim values in the case of alloy 97NT-2. Good agreement for the composition of the VT2-2 type alloy was also obtained, except that the actual analysis showed the presence of appreciable amounts of nickel and tungsten.

The compositions of other alloys used for evaluating the properties of the high-carbon alloys are also included in table I.

Heat Treatment

The samples of the NT-2 type alloy were solution treated by water quenching after 1/2 hour at 2260° F. This treatment was recommended because the tests at 1500° and 1600° F had shown it to be beneficial to the strength of this alloy (references 2, 3 and 4).

Because prior tests at the lower temperatures had shown the VT2-2 type alloy to have the best properties in the as-cast condition, the samples were not heat treated for the tests at 1700° and 1800° F.

EXPERIMENTAL PROCEDURE

The tests used in this investigation included sufficient rupture tests at 1700° and 1800° F to determine the rupture strengths at 100 and 400 hours, metallographic examination, and hardness tests.

The rupture tests of less than 10 hours duration were made in a hydraulic tensile machine after the specimen had been at the testing temperature for 1 hour. The longer duration rupture tests were run in single specimen units. The specimens were held at temperature for approximately 24 hours before application of the stress to allow for adjustment of the temperature. The stress was applied through a simple beam and a system of knife edges.

Metallographic samples of the original material and the specimens from the longest duration rupture tests at each temperature were photographed at 100X and 1000X. Samples were macroetched to show grain size. No original specimens of alloys 97NT-2 and 113VT2-2 were available for macroetching, so fractured rupture specimens were used.

Vickers hardness determinations were made on the samples used for metallographic studies.

RESULTS

The rupture-test data and the rupture strengths are shown in table II. The rupture strengths were taken from the usual curves of log stress against log rupture time in figures 1 and 2. The straight-line curves break, or show a change in slope, between 40 and 100 hours.

The total deformation to fracture decreased with increasing time for fracture except for 128VT2-2 alloy at 1800° F. At both 1700° and 1800° F the VT2-2 type alloy had considerably higher ductility than alloy 97NT-2. The higher ductility specimens had irregular fractures and necked-down non-uniformly. These effects are common in materials, such as these cast specimens, with only a few grains in the cross section of the gage length. Typical examples of the grain size of the specimens are shown in figure 3.

Photomicrographs of the structures of the specimens before and after rupture testing are shown in figures 4 and 5. In the original condition both alloys had similar dendritic patterns of the excess constituents, typical for cast alloys of the type under consideration. After rupture testing there was considerable precipitation in the 97NT-2 specimens and only a slight amount in the VT2-2 type alloy. The precipitate was slightly more agglomerated in the specimens of 97NT-2 alloy tested at 1800° F than in those tested at 1700° F.

Figures 4(c) and (d) show the structures of two 97NT-2 alloy specimens which had quite divergent times for rupture. These show no direct reason for the cause of the erratic rupture times for the two specimens. The specimen tested under 11,000 psi, however, had more areas of finely divided excess constituent. The orientation of the excess constituents was also different.

The hardness of the samples used for metallographic examination is given with the photomicrographs. Both alloys increased in hardness as a result of rupture testing. This was presumably due to precipitation of excess constituents during testing.

DISCUSSION OF RESULTS

Table III was prepared to show the relationship between the rupture-test characteristics of the high-carbon NT-2 type and VT2-2 type alloys and other alloys previously tested. The following trends are shown:

1. The high-carbon modified N155 alloy, 97NT-2, had higher rupture strengths than the modified Vitallium alloy, type VT2-2, except for short time periods at 1700° F.

2. Both the 97NT-2 alloy and the VT2-2 type alloy were considerably stronger for time periods up to 100 hours than the best alloy, X-40, previously tested at 1700° and 1800° F (reference 1). This superiority decreased with time for rupture so that the rupture strengths of X-40 and 97NT-2 approached one another and X-40 was slightly stronger at 1000 hours. The VT2-2 type alloy was weaker than X-40 for time periods greater than about 100 hours.

3. The high-carbon Vitallium plus 2 percent tantalum alloy, type VT2-2, had higher rupture strengths than those obtained from standard Vitallium alloy in the previous work at 1700° and 1800° F (reference 1) for time periods up to about 1000 hours. The low-carbon standard alloy would apparently be better for longer time periods.

4. The ductility of X-40 alloy in the rupture tests at 1700° F was higher than that of the high-carbon NT-2 and VT2-2 types. At 1800° F the ductility of the VT2-2 type alloy was similar to that of X-40 alloy while the NT-2 type alloy had lower ductility.

5. The high-carbon Vitallium plus tantalum alloy, type VT2-2, had more elongation in the rupture tests than standard Vitallium except for time periods up to about 100 hours.

There are, however, certain factors which should be considered in connection with these results:

1. A rather high-temperature solution treatment was used on the 97NT-2 alloy. No data are available at 1700° and 1800° F regarding the effect of solution treatments on the other alloys considered.

2. Mold temperature and pouring temperature are known to affect the strength and ductility at high temperatures. Section size of castings also influences the rupture strength. This type of information is not available for the Vitallium and X-40 alloys. Likewise, no systematic work has been done on these variables at 1700° and 1800° F to act as guide in evaluating the data.

The microstructures were similar to those of most of the cast alloys previously investigated (reference 1). The precipitation in alloy 97NT-2 agreed with previous findings that such precipitation was associated with higher strength and lower ductility. The erratic results from certain tests are believed to be due to orientation differences in the relatively few grains composing the gage length of the specimens.

Correlation of Results

An approximation of the effect of temperature on the two high-carbon alloys used in this investigation can be made by use of the data at 1500° and 1600° F given in references 2, 3, and 4. The curves of log stress against log rupture time at 1500° and 1600° F are shown together with the curves at 1700° and 1800° F in figures 6 and 7 for the high-carbon NT-2 and VT2-2 type alloys. The rupture strengths defined by these curves are summarized in tables IV and V and are shown graphically as a function of temperature in figures 8 and 9. Tables VI and VII summarize the data used from the references. The following comments should be considered with respect to the available data on the effect of temperature on these alloys:

1. The strength of the high-carbon VT2-2 Vitallium-type alloy drops more rapidly with temperature than the strength of the high-carbon NT-2 type alloy. The superiority of the VT2-2 type alloy at 1500° and 1600° F therefore does not carry over to 1700° and 1800° F as was suggested in reference 2.

2. The ductility of the high-carbon VT2-2 type alloy was higher at all four temperatures than for the high-carbon NT-2 type alloy. Both alloys had higher ductility at 1700° and 1800° F than at the lower temperatures.

3. The curves of rupture strength against temperature all show an inflection between 1500° and 1700° F. The data are not sufficient to determine if this inflection point lies between 1500° and 1600° F or between 1600° and 1700° F. For this reason it was necessary to use straight lines to connect the points. This inflection is probably due to a structural change caused by the increasing temperature.

4. The length of time that specimens were held at temperature prior to application of the stress may also have influenced the rupture strengths by an aging effect. Other investigations for the NACA have shown that the properties of many of the heat-resisting alloys can be influenced to a pronounced degree by aging at temperatures above 1200° F prior to testing. Similar effects have been shown from aging at temperatures above 1500° F by the M.I.T. work on alloys of the type considered in this investigation.

In the tests at Michigan the specimens were at the test temperature nearly 24 hours before the stress was applied. In the early 1500° F tests at M.I.T., specimens were held at temperature from 10 to 50 hours without stress (reference 3). Later tests were held at temperature 1 hour before application of the stress (reference 4).

5. It is conceivable that such testing variables may be partially responsible for the inflection in the curves of rupture strength against temperature. The more probable explanation, however, is that structural alterations caused by the higher temperature change the rupture test characteristics rather than any testing procedure variation.

Curves of Stress against Log Rupture Time

Recently E. S. Machlin and A. S. Nowick of the staff of the Aircraft Engine Research Laboratory of the NACA at Cleveland, Ohio, made a theoretical study of the rupture test (reference 5). Their derived equation indicates that the correct relationship between stress and rupture time should be a straight line when stress is plotted against the logarithm of the rupture time. Almost all data have previously been shown as straight lines when the logarithm of the stress was plotted against the logarithm of the time for rupture.

The data available for the high-carbon NT-2 and VT2-2 type alloys are shown as semi-logarithmic curves in figures 10 and 11. These curves are comparable with the logarithmic curves of figures 1, 2, 6, and 7. Straight lines resulted over the whole range in rupture time without the breaks shown by the logarithmic curves at 1700° and 1800° F. On the other hand, the erratic points at 1500° and 1600° F show considerably more deviation from the curves than was apparent in the log-log curves.

The straight-line semi-log relation fits the data better over the complete stress range at 1700° and 1800° F than do the logarithmic curves. This suggests that the theoretical equation relating the logarithm of the rupture time to the stress may be more nearly correct than the logarithmic plots now used.

It is difficult to appraise the factors involved so as to judge the relative correctness of the two methods of presenting the data. In this case, and probably in most cases, the rupture strengths obtained from either type of plot will agree closely, as is shown by table VIII. The real answer will depend on whether the change in slope of the log-log curves reflects a physical difference in the material or manner of fracture caused by exposure to stress and temperature. If such changes in structure are occurring, then they are masked by the semilogarithmic relationship and the log-log curve better represents the experiments.

CONCLUSIONS

Evaluation of rupture-test data at 1700° and 1800° F for a high-carbon Cr-Ni-Co-Mo-W-Ta modification of N155 alloy, NT-2 type alloy, and for a high-carbon plus tantalum modification of Vitallium, type VT2-2 alloy, leads to the following conclusions:

1. The high-carbon NT-2 type alloy heat treated at 2260° F has higher rupture strength at 1700° and 1800° F than the high-carbon VT2-2 type alloy in the as-cast condition except for relatively short time periods for rupture. This difference in strength may have been due to the heat treatment of the NT-2 alloy, although as-cast VT2-2 alloy was superior to the heat-treated NT-2 alloy at 1500° and 1600° F.

2. For time periods up to about 500 hours the high-carbon NT-2 type alloy has better rupture strength than the best alloy, X-40, previously tested at these temperatures.

3. High-carbon VT2-2 Vitallium-type alloy has higher rupture strength than standard Vitallium at 1700° and 1800° F for time periods up to about 1000 hours.

4. The ductility of the high-carbon alloys in the rupture test at 1700° and 1800° F compares favorably with those of X-40 and standard Vitallium.

5. An inflection occurs in the curves of rupture strength against temperature for the high-carbon alloys, indicating a structural change in the temperature range between 1500° and 1700° F.

6. A single straight line best represents the rupture test data at 1700° and 1800° F when plotted to semi-log coordinates of stress against rupture time. On the log-log plot the data are best represented by two intersecting straight lines.

7. The strength relationships developed by this investigation on the basis of chemical composition may not be typical, due to lack of consideration of such variables as mold temperature, pouring temperature, section size, heat treating, and aging.

Department of Engineering Research,
University of Michigan,
Ann Arbor, Mich., May 7, 1946.

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TABLE I

CHEMICAL COMPOSITION OF EXPERIMENTAL HEAT-RESISTANT ALLOYS

Alloy	Analysis made by	Chemical composition (percent)									
		C	Cr	Ni	Co	Mo	W	Ta	Mn	Si	Fe
97NT-2	MIT	0.97	21	30	21	3	2.2	2	----	----	----
	UC & C	0.96	20.73	29.78	22.40	3.20	2.18	[a]1.77	0.92	0.38	17.65
113VT2-2	MIT	1.13	23	----	67	6	----	2	----	----	----
	UC & C	1.17	23.14	3.08	63.34	5.64	0.24	[a]1.85	----	----	----
128VT2-2	MIT	1.28	23	----	67	6	----	2	----	----	----
	UC & C	1.27	22.83	6.50	57.68	5.31	0.50	[a]2.15	----	----	----
X-40	(b)	.48	25.12	9.69	55.23	----	7.23	----	0.64	0.72	0.55
Vitallium	(b)	.24	27.60	3.06	Balance	5.13	----	----	.98	.63	1.76

MIT Massachusetts Institute of Technology.
UC & C Union Carbide and Carbon Research Laboratories, Inc.

[a]Tantalum + columbium.

[b]See reference 1.

TABLE II

RUPTURE-TEST DATA AT 1700° AND 1800° F FOR HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY, TYPE NT-2, AND HIGH-CARBON VITALLIUM PLUS 2 PERCENT TANTALUM ALLOY, TYPE VT2-2

Alloy	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
97NT-2	1700	27,000	1.37	22	18.3
		19,000	88.0	7	11.5
		17,000	134.5	6	8.5
		15,000	412.0	2	3.9
97NT-2	1800	21,000	1.38	20	34.0
		15,000	48.5	8	12.1
		14,000	61.0	6	7.1
		13,000	490.0	3	4.7
		11,000	329.5	4	10.9
113VT2-2	1700	24,000	6.0	20	18.0
		17,000	108.0	14	20.5
		15,000	173.0	19	25.7
		14,000	252.0	12	20.2
		13,000	651.0	9	12.8
128VT2-2	1800	20,000	1.33	22	29.0
		12,500	66.5	19	33.0
		11,000	102.0	20	37.0
		9,000	300.0	20	30.9

Alloy	Test temperature (°F)	Rupture strengths: Stress for rupture in indicated time periods (psi)				
		1 hr	10 hr	100 hr	400 hr	1000 hr
97NT-2	1700	27,500	23,000	18,250	15,000	[a]13,000
113VT2-2	1700	30,000	23,000	17,000	13,000	11,000
97NT-2	1800	21,500	17,250	13,000	10,500	[a]9,200
128VT2-2	1800	21,000	15,500	11,000	8,400	[a]6,900

[a]Estimated.

TABLE III

RUPTURE-TEST CHARACTERISTICS OF EXPERIMENTAL HEAT-RESISTANT ALLOYS AT 1700° AND 1800° F

[Data for X-40 and Vitallium taken from reference 1.]

Alloy	Temperature (°F)	Stress for rupture in indicated time periods				
		1 hr	10 hr	100 hr	400 hr	1000 hr
97NT-2	1700	27,500	23,000	18,250	15,000	[a]13,000
113VT2-2	1700	30,000	23,000	17,000	13,000	11,000
X-40	1700	24,000	20,000	17,000	15,500	14,500
Vitallium	1700	22,500	17,000	13,000	11,000	10,000
97NT-2	1800	21,500	17,250	13,000	10,500	[a]9,200
128VT2-2	1800	21,000	15,500	11,000	8,400	[a]6,900
X-40	1800	15,500	13,000	11,300	10,300	9,800
Vitallium	1800	16,500	12,500	9,400	7,900	7,000
		Elongation in 1 in. to rupture in indicated time periods[a] (percent)				
97NT-2	1700	22	------	6	2	------
113VT2-2	1700	------	20	15	10	8
X-40	1700	45	35	23	22	25
Vitallium	1700	33	33	10	7	5
97NT-2	1800	20	------	6	4	------
128VT2-2	1800	22	------	20	20	------
X-40	1800	30	30	20	12	------
Vitallium	1800	40	------	12	12	12

[a]Estimated.

TABLE IV

EFFECT OF TEMPERATURE ON THE RUPTURE STRENGTH AND DUCTILITY

OF HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY, TYPE NT-2

[Data at 1500° and 1600° F taken from reference 2.]

Alloy	Test temp. (°F)	Stress for rupture (psi)				Elongation to rupture[a] (percent)			
		10 hr	100 hr	400 hr	1000 hr	10 hr	100 hr	400 hr	1000 hr
97NT-2	1500	-------	30,000	25,750	23,000	------	5	3	--------
102NT-2	1600	32,000	25,000	21,500	19,500	6	3	3	3
97NT-2	1700	23,000	18,250	15,000	[a]13,000	------	6	2	--------
97NT-2	1800	17,250	13,000	10,500	[a]9,200	------	6	4	--------

[a]Estimated.

TABLE V

EFFECT OF TEMPERATURE ON THE RUPTURE STRENGTH AND DUCTILITY

OF HIGH-CARBON VITALLIUM PLUS 2 PERCENT TANTALUM ALLOY, TYPE VT2-2

(1.11 to 1.28 percent carbon)

[Data at 1500° and 1600° F taken from references 2 and 3.]

Test temperature (°F)	Stress for rupture (psi)			Elongation to rupture[a] (percent)		
	100 hr	400 hr	1000 hr	100 hr	400 hr	1000 hr
1500	34,000	28,500	25,000	9	7	6.5
1600	27,000	22,500	19,750	8	8	8
1700	17,000	13,000	11,000	15	10	8
1800	11,000	8,400	[a]6,900	20	20	-------

[a]Estimated.

TABLE VI

COMPOSITION AND RUPTURE-TEST DATA FOR HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY, TYPE NT-2, AT 1500° AND 1600° F

[Data taken from reference 2]

Chemical Composition

Alloy	Chemical composition (percent)									
	[a]C	[a]N_2	Mn	Si	Cr	Ni	Co	Mo	Ta	W
97NT-2	0.97	[b]0.057	1.5	1	20	30	21	3	2	2.2
99NT-2	.99	(b)	1.5	1	20	30	21	3	2	2.2
102NT-2	1.02	(b)	1.5	1	20	30	21	3	2	2.2

[a]Actual analysis; other alloys are aim percentages.
[b]Residual nitrogen; no nitrogen added.

Rupture-Test Data

Alloy	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation (percent)	Reduction of area (percent)
97NT-2	1500	30,000	79.8	4.8	2.2
	1500	30,000	99.0	5.7	4.0
	1500	25,000	489.0	3.1	1.3
99NT-2	1500	30,000	109.5	4.3	1.2
	1500	25,000	542.4	3.2	1.8
102NT-2	1500	30,000	105	5.2	1.2
99NT-2	1600	20,000	289.0	2.0	1.0
102NT-2	1600	30,000	17.2	6.3	4.1
	1600	25,000	148.0	2.8	1.2
	1600	20,000	805	2.8	1.0

TABLE VII

COMPOSITION AND RUPTURE-TEST DATA FOR HIGH-CARBON VITALLIUM

PLUS 2 PERCENT TANTALUM ALLOY, TYPE VT2-2, AT 1500° AND 1600° F

Chemical Composition

Alloy	Mold temperature (°F)	Metal temperature (°F)	Chemical composition (percent)						Data source (reference)
			[a]C	[a]N_2	Cr	Co	Mo	Ta	
111VT2-2	1850	2534-2606	1.11	[b]0.062	23	67	6	2	2
125VT2-2	1850	2534-2606	1.25	(b)	23	67	6	2	2
111VT2-2(#2)	1850	2534-2588	1.11	(b)	23	67	6	2	3
113VT2-2(#2)	1850	2534-2588	1.13	(b)	23	67	6	2	3

[a]Actual analysis; other alloys are aim percentages.
[b]Residual nitrogen; no nitrogen added.

Rupture-Test Data

Alloy	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation (percent)	Reduction of area (percent)	Data source (reference)
111VT2-2	1500	30,000	297.3	8.3	3.7	2
		25,000	1093.4	6.5	2.0	2
111VT2-2(#2)	1500	35,000	91.3	10.3	6.9	3
113VT2-2(#2)	1500	35,000	69.0	11.1	10.6	3
		35,000	65.2	9.6	8.1	3
		30,000	321.0	7.1	9.7	3
125VT2-2	1500	30,000	152.0	7.9	3.7	2
		30,000	247.5	7.1	2.5	2
111VT2-2	1600	25,000	122.2	6.8	3.2	2
		20,000	960.0	8.9	2.0	2
111VT2-2(#2)	1600	25,000	136.7	7.9	4.9	3
113VT2-2(#2)	1600	30,000	85.4	8.8	8.1	3
		25,000	197.0	8.1	7.8	3
		25,000	188.0	8.3	4.9	3
		20,000	890.0	8.1	4.9	3
125VT2-2	1600	25,000	131.9	6.4	3.5	3
		25,000	129.7	8.2	4.1	3

TABLE VIII

COMPARATIVE RUPTURE STRENGTHS FOR HIGH-CARBON NT-2 AND VT2-2 TYPE ALLOYS FROM LOG-LOG AND SEMI-LOG CURVES OF STRESS AGAINST RUPTURE TIME

Alloy	Test temperature (°F)	Stress for rupture in indicated time periods (psi)					Method of plotting
		1 hr	10 hr	100 hr	400 hr	1000 hr	
97NT-2	1500	------	------	30,000	25,750	23,000	log-log
97NT-2	1500	------	------	30,000	25,750	23,000	semi-log
102NT-2	1600	------	32,000	25,000	21,500	19,500	log-log
102NT-2	1600	------	32,000	25,500	21,500	19,000	semi-log
97NT-2	1700	27,500	23,000	18,250	15,000	[b]13,000	log-log
97NT-2	1700	27,500	23,750	18,000	15,000	[b]13,000	semi-log
97NT-2	1800	21,500	17,250	13,000	10,500	[b]9,200	log-log
97NT-2	1800	22,250	17,750	13,250	10,500	[b]8,800	semi-log
[a]VT2-2	1500	------	------	34,000	28,500	25,000	log-log
[a]VT2-2	1500	------	------	34,000	28,750	25,000	semi-log
[a]VT2-2	1600	------	------	27,000	22,500	19,750	log-log
[a]VT2-2	1600	------	------	26,250	22,250	19,500	semi-log
113VT2-2	1700	30,000	23,000	17,000	13,000	11,000	log-log
113VT2-2	1700	28,250	22,500	17,000	13,500	11,000	semi-log
128VT2-2	1800	21,000	15,500	11,000	8,400	[b]6,900	log-log
128VT2-2	1800	20,500	16,000	11,250	8,500	[b]6,500	semi-log

[a]See table VII for carbon contents.
[b]Estimated.

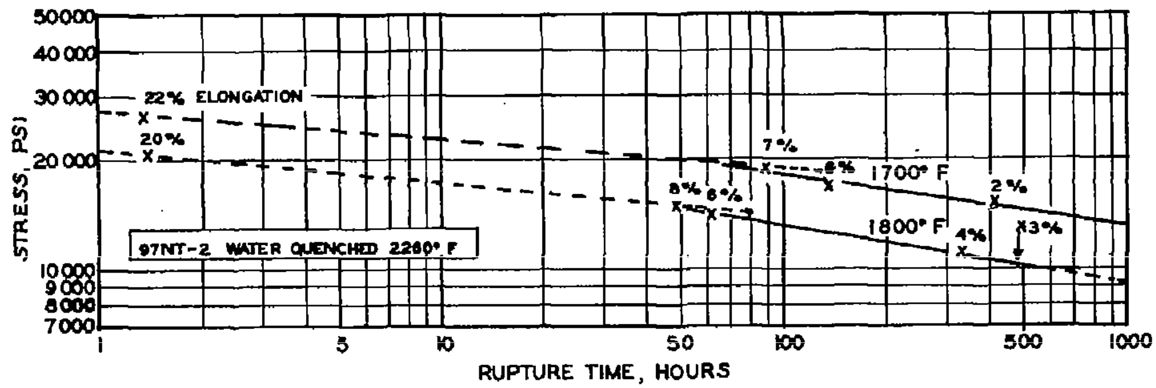


FIGURE 1.- STRESS-RUPTURE TIME CURVES AT 1700° AND 1800° F FOR HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY NT-2.

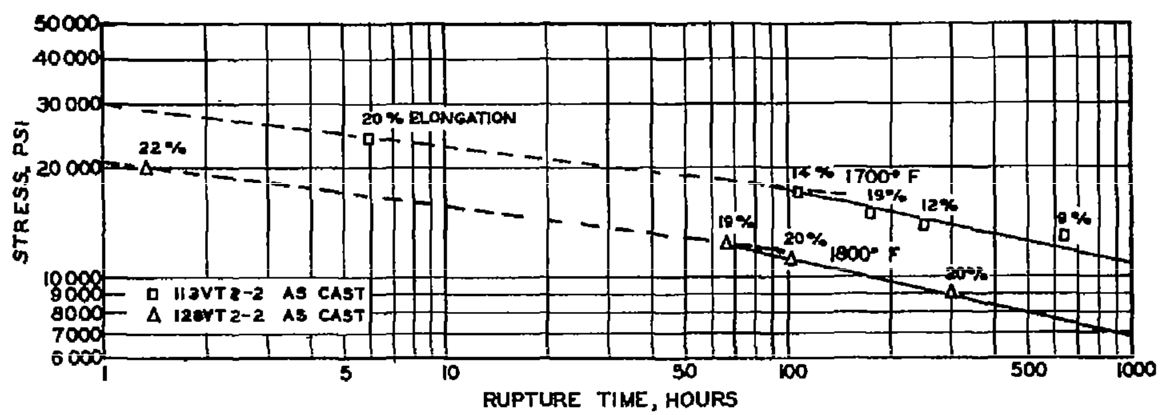
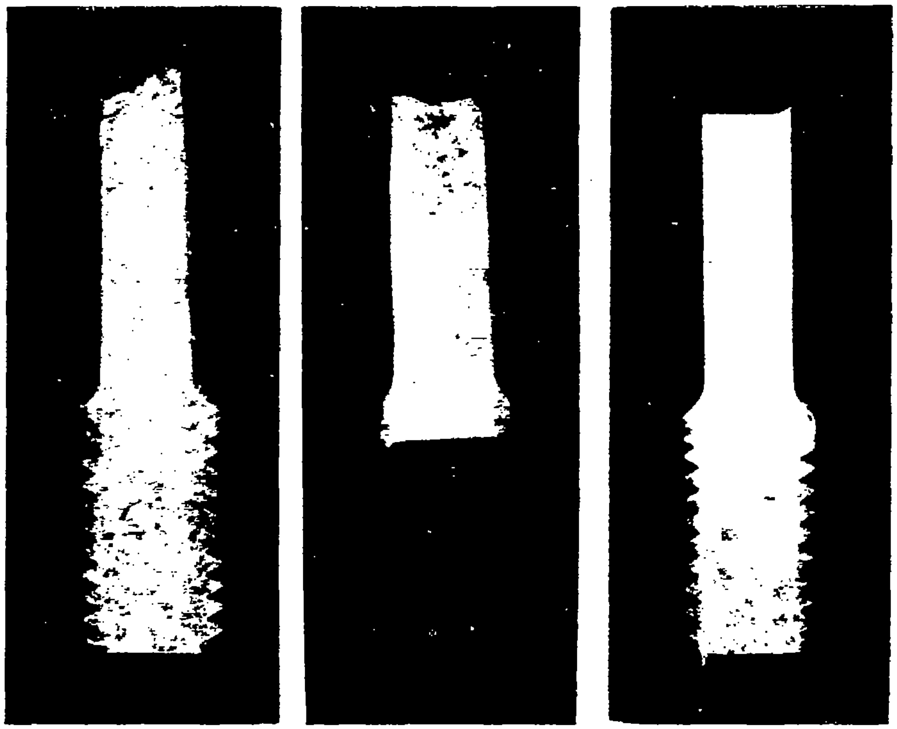


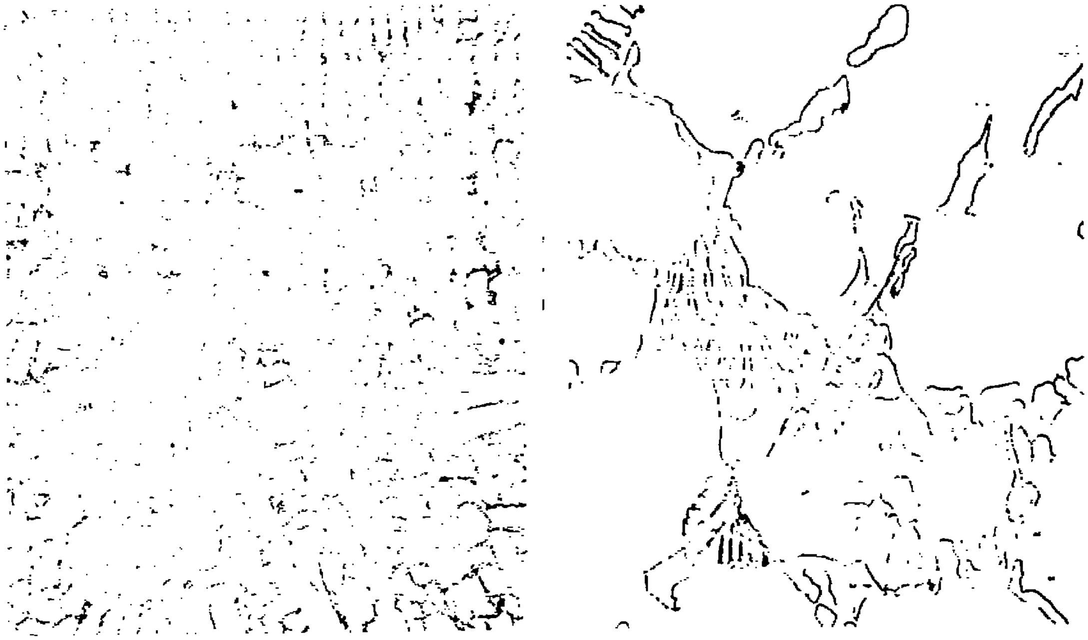
FIGURE 2.- STRESS-RUPTURE TIME CURVES AT 1700° AND 1800° F FOR HIGH-CARBON VITALLIUM + 2 PERCENT TANTALUM ALLOY VT2-2.



97NT-2 113VT2-2 128VT2-2

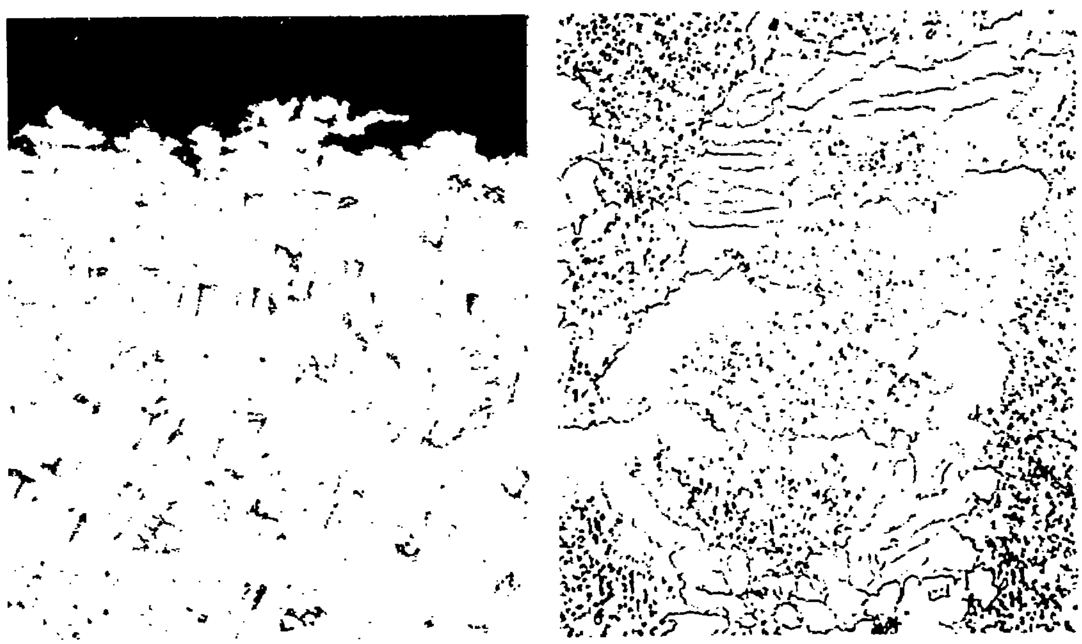
Magnification - 2X

FIGURE 3.- MACROSTRUCTURES OF HIGH-CARBON MODIFIED N155 AND MODIFIED VITALLIUM ALLOYS.



100X 1000X

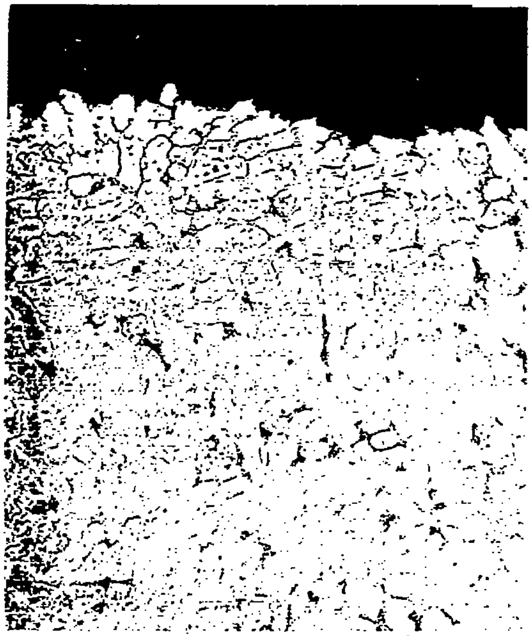
(a) Original - Cast + water quenched after ½ hour at 2260° F.
Electrolytic Oxalic acid etch - Vickers hardness 270.



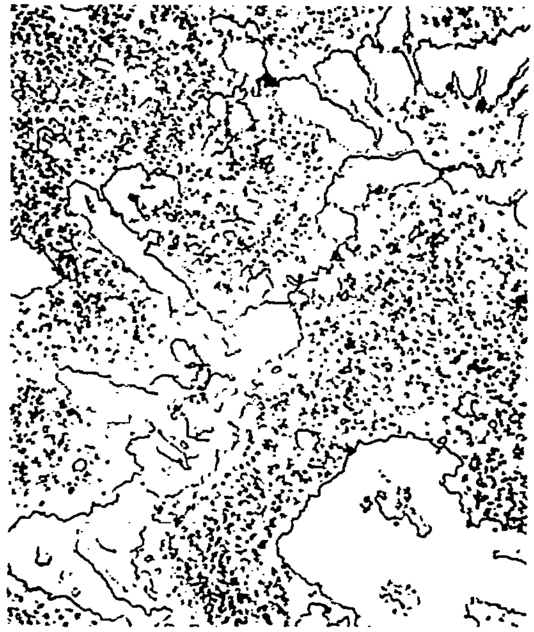
Fracture - 100X Interior - 1000X

(b) Rupture specimen - 412 hours at 1700° F under 15,000 psi.
Electrolytic Oxalic acid etch - Vickers hardness 318.

FIGURE 4.- MICROSTRUCTURES OF HIGH-CARBON
Ni-Cr-Co-Mo-W-Ta ALLOY 97NT-2.



Fracture - 100X



Interior - 1000X

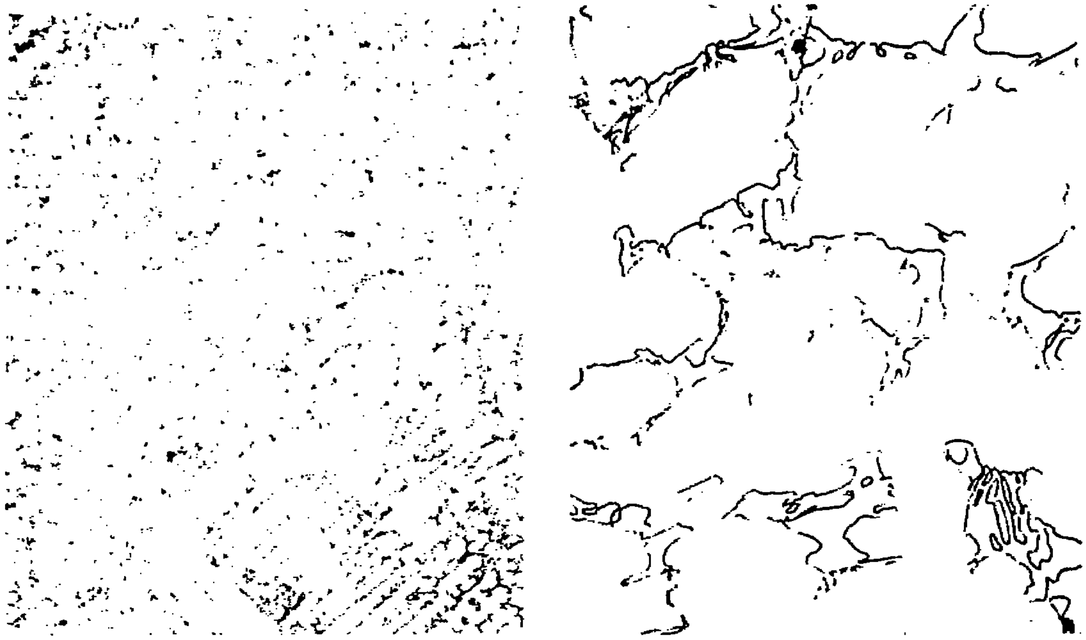
(c) Rupture specimen - 490 hours at 1800° F under 13,000 psi.
Electrolytic Oxalic acid etch - Vickers hardness 311.

Fracture - 100X

Interior - 1000X

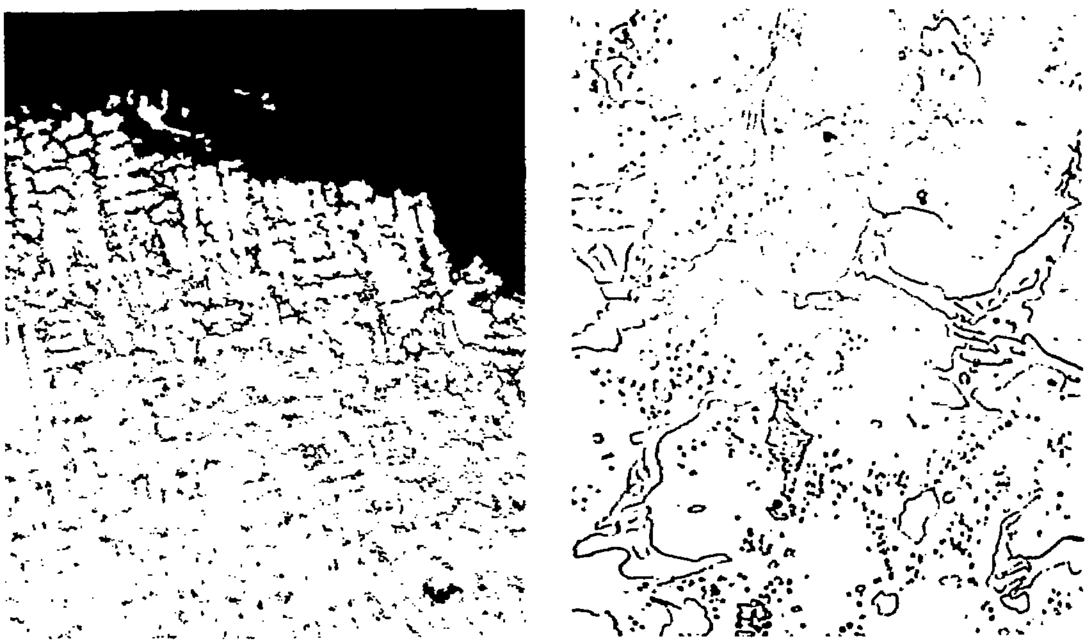
(d) Rupture specimen - 329.5 hours at 1800° F under 11,000 psi.
Electrolytic Oxalic acid etch - Vickers hardness 306.

FIGURE 4 (CONTINUED).- MICROSTRUCTURES OF HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY 97NT-2.



100X 1000X

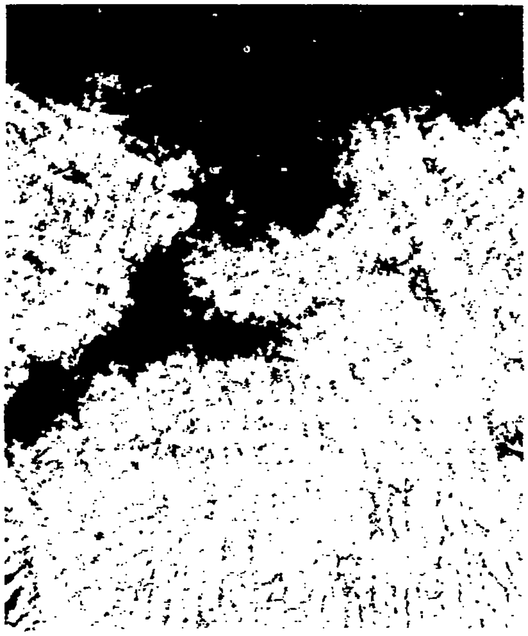
(a) Original - As cast.
Electrolytic Oxalic acid etch - Vickers hardness 395.



Fracture - 100X Interior - 1000X

(b) Rupture specimen - 651 hours at 1700° F under 13,000 psi.
Electrolytic Oxalic acid etch - Vickers hardness 442.

FIGURE 5.- MICROSTRUCTURES OF HIGH-CARBON VITALLIUM + 2 PERCENT TANTALUM ALLOY VT2-2.

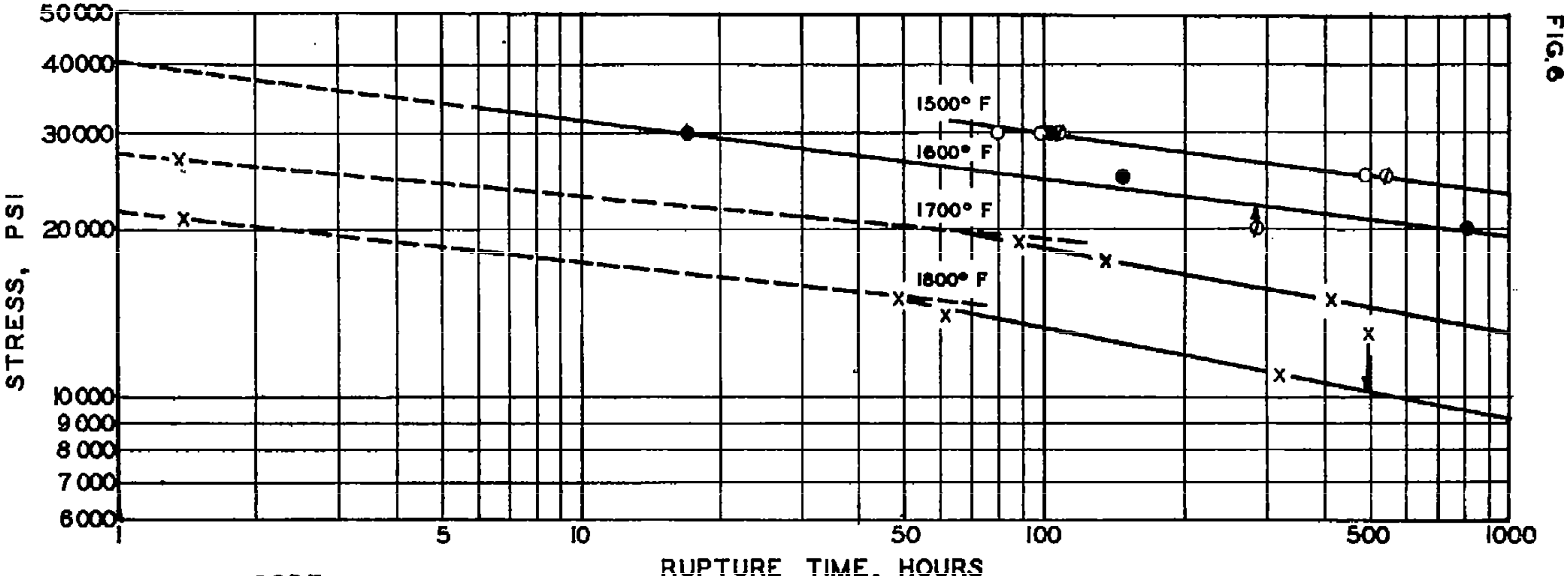


Fracture - 100X

Interior - 1000X

(c) Rupture specimen - 300 hours at 1800° F under 9000 psi.
Electrolytic Oxalic acid etch - Vickers hardness 438.

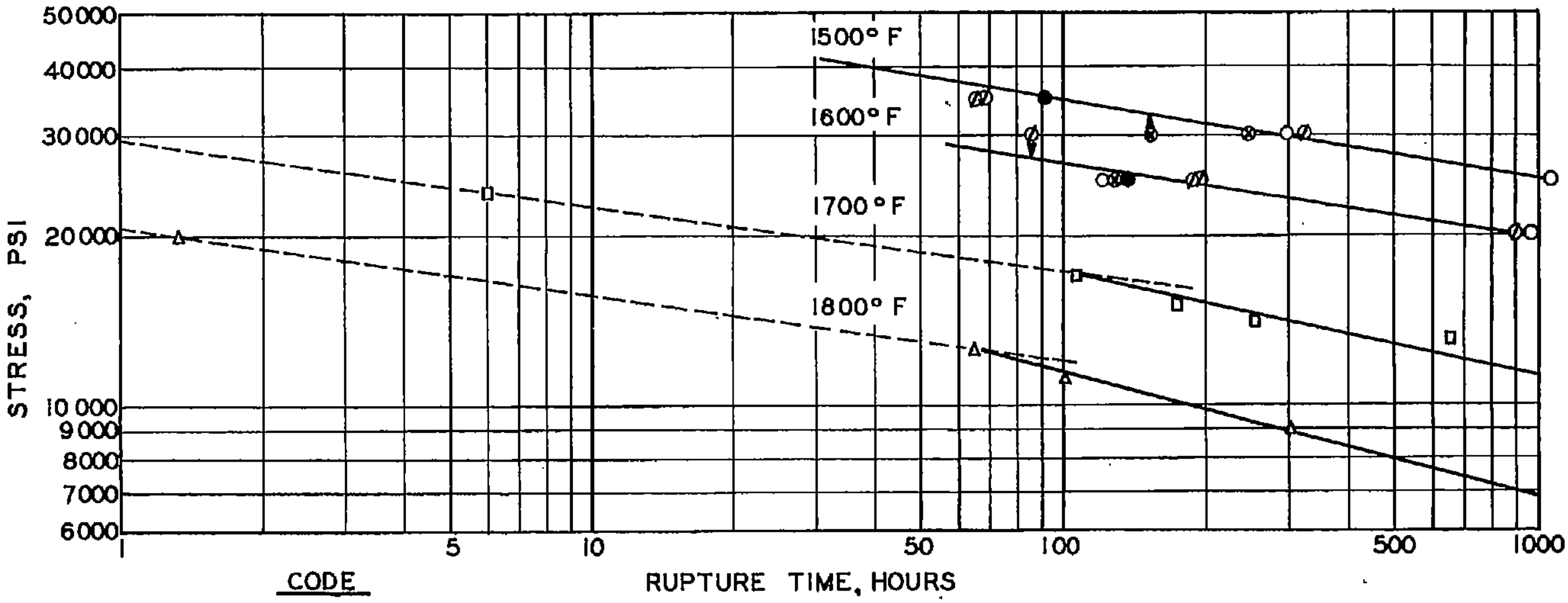
FIGURE 5.(CONTINUED).- MICROSTRUCTURES OF HIGH-CARBON VITALLIUM + 2 PERCENT TANTALUM ALLOY VT2-2.



CODE		
SYMBOL	ALLOY	DATA SOURCE
O	97 NT-2	REFERENCE 2
Ø	99 NT-2	REFERENCE 2
●	102 NT-2	REFERENCE 2
X	97 NT-2	U OF M

HEAT TREATMENT: WATER QUENCHED 2260° F

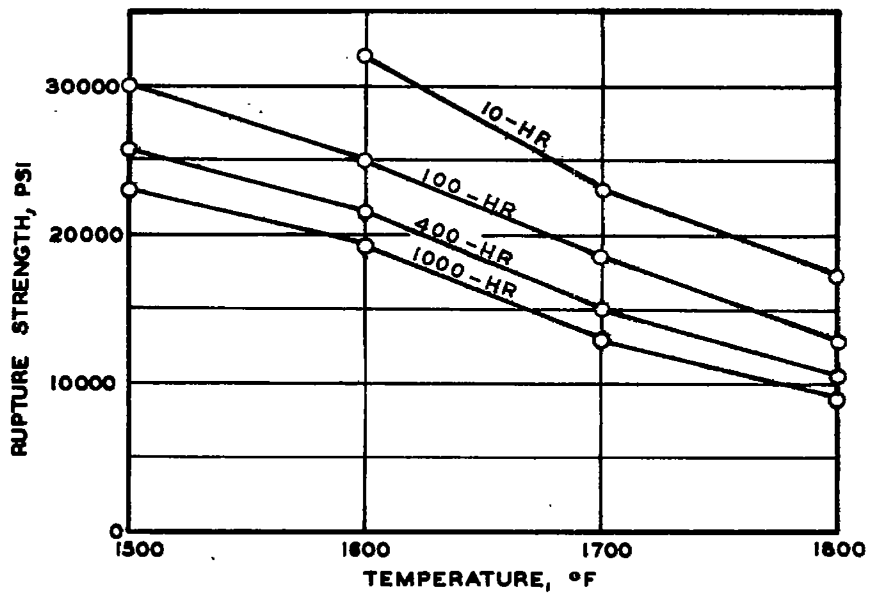
FIGURE 6.-STRESS-RUPTURE TIME CURVES FOR HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY NT-2.



CODE

SYMBOL	ALLOY	DATA SOURCE
○	111VT2-2	REFERENCE 2
●	111VT2-2 (No.2)	REFERENCE 3
⌀	113VT2-2 (No.2)	REFERENCE 3
⊗	125VT2-2	REFERENCE 2,3
□	113VT2-2	U OF M
Δ	128VT2-2	U OF M

FIGURE 7.-STRESS-RUPTURE TIME CURVES FOR HIGH-CARBON VITALLIUM+2 PERCENT TANTALUM ALLOY VT2-2.



HEAT TREATMENT: WATER QUENCHED 2260° F

FIGURE 8.- EFFECT OF TEMPERATURE ON THE RUPTURE STRENGTH OF HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY NT-2.

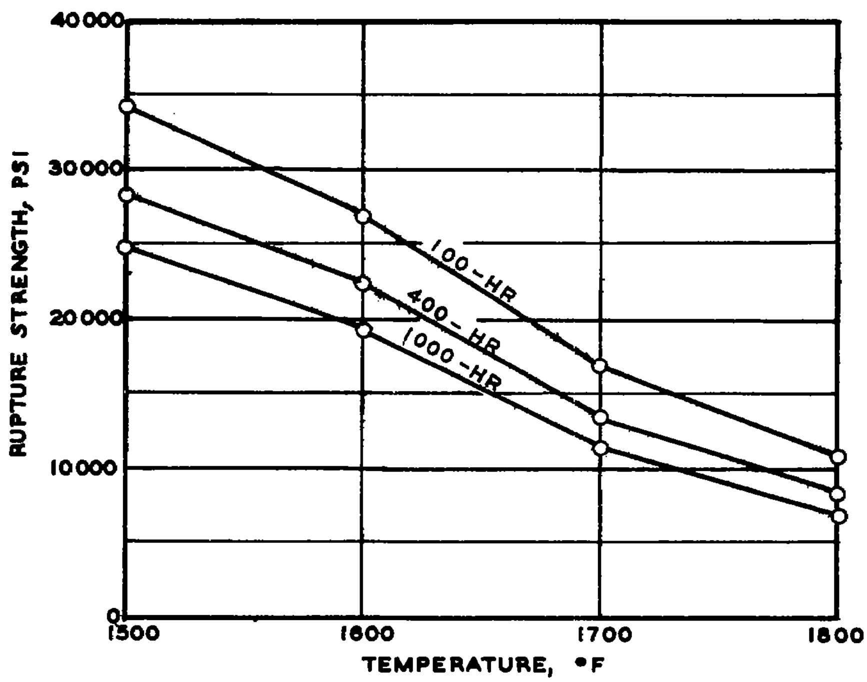


FIGURE 9.- EFFECT OF TEMPERATURE ON THE RUPTURE STRENGTH OF HIGH-CARBON VITALLIUM + 2 PERCENT TANTALUM ALLOY VT2-2.

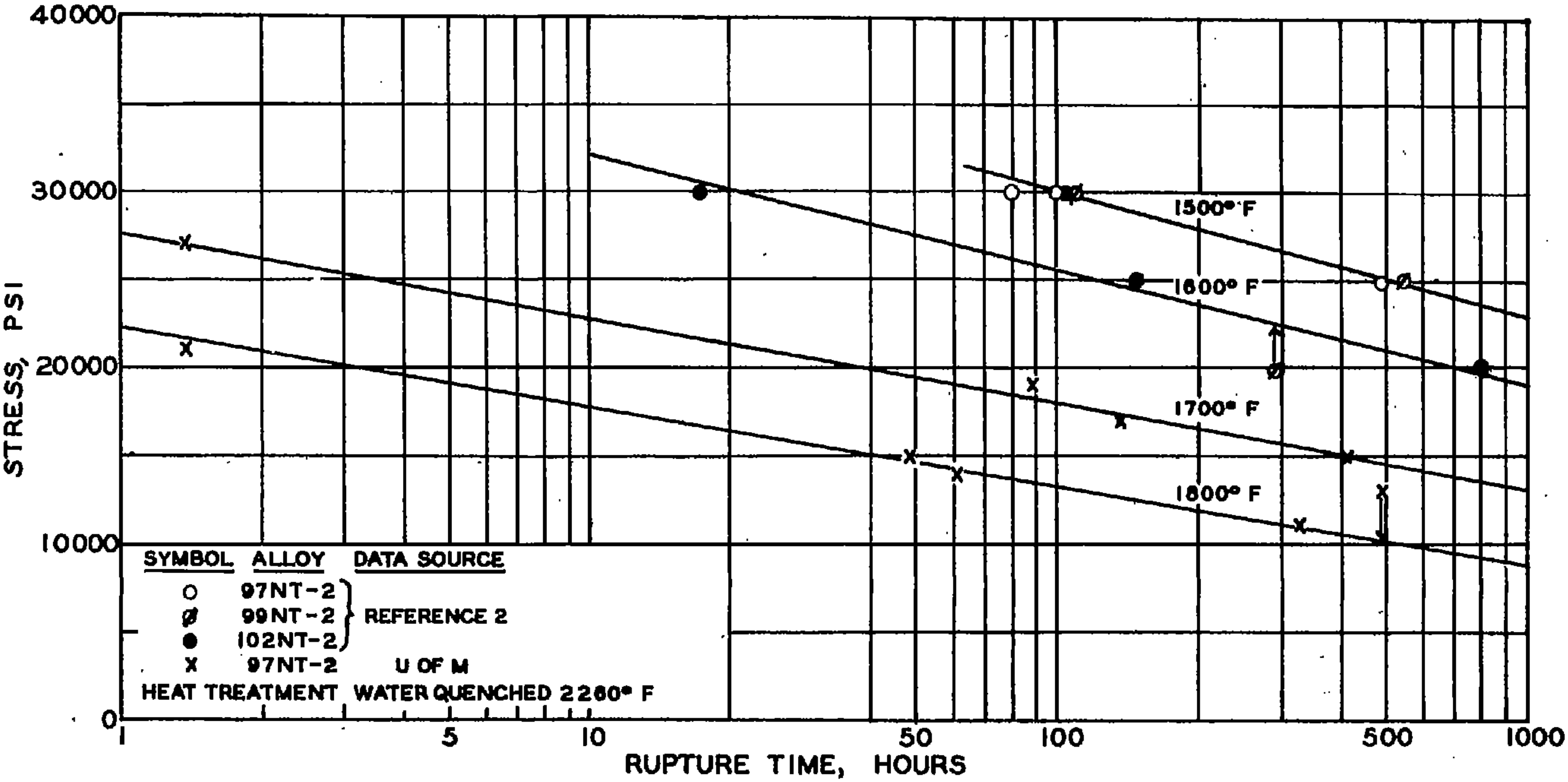


FIGURE 10.- STRESS-LOG RUPTURE TIME CURVES FOR HIGH-CARBON Ni-Cr-Co-Mo-W-Ta ALLOY NT-2.

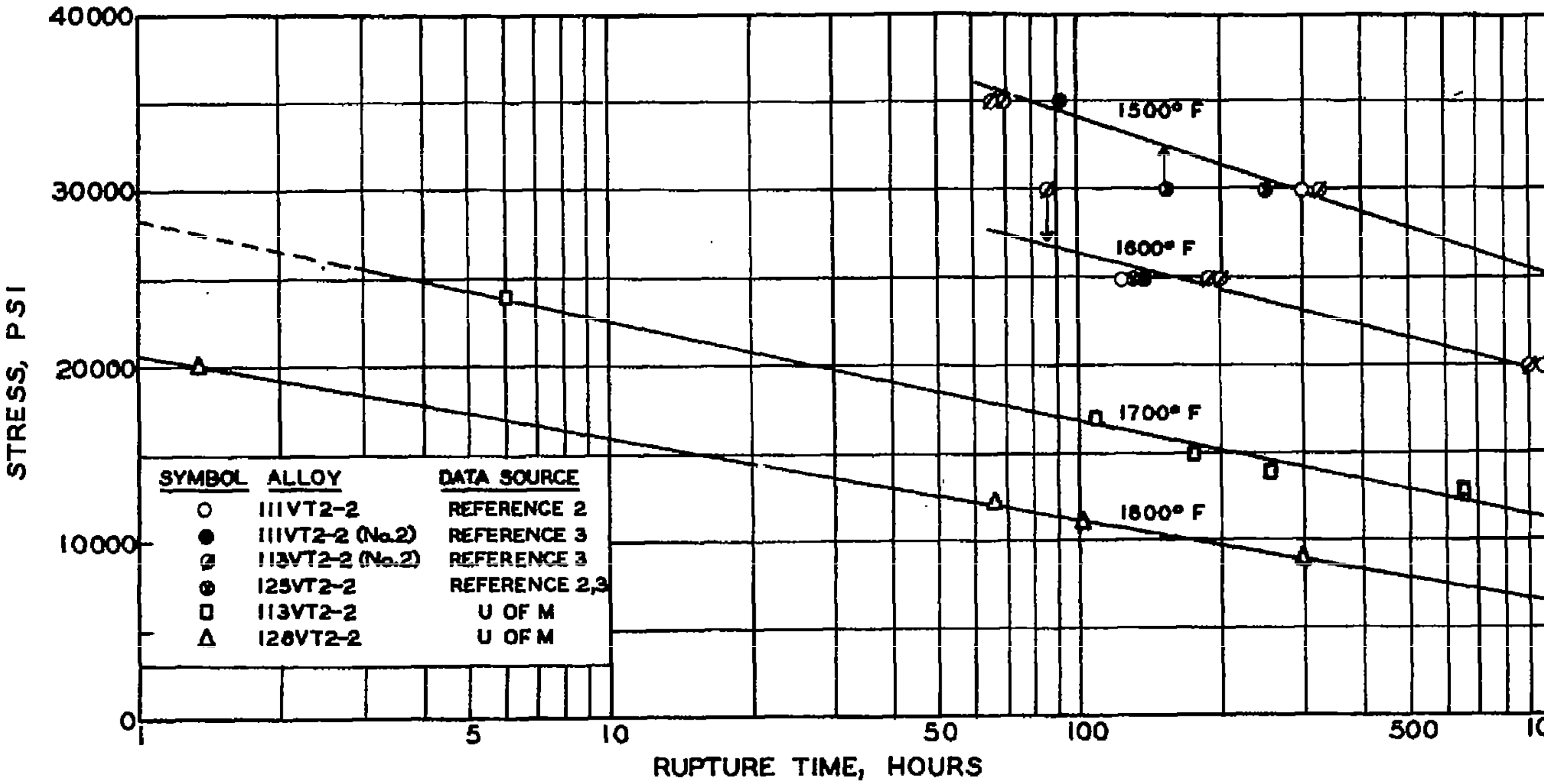


FIGURE 11.- STRESS-LOG RUPTURE TIME CURVES FOR HIGH-CARBON VITALLIUM + 2 PERCENT TANTALUM ALLOY VT2-2.